CLAIMS

What is claimed is:

1. In a system for acoustic logging of an earth formation comprising a transmitter creating acoustic energy and a plurality of receivers recording time domain representations of the acoustic energy as it traverses the earth formation, a method of signal processing to determine acoustic velocity as a function of frequency comprising:

converting the time domain representations of the acoustic energy into frequency domain representations;

creating a correlation matrix from amplitudes within the frequency domain representations at corresponding frequencies;

finding an orthogonal basis of the correlation matrix comprising a plurality of component functions;

removing at least one component function to create a subspace; and

multiplying a test vector and the subspace, the test vector based on an estimated acoustic velocity of the earth formation, to determine whether the estimated acoustic velocity substantially matches the actual earth formation acoustic velocity.

2. The method of signal processing to determine acoustic velocity as a function of frequency as defined in claim 1 wherein converting the time domain representations of the acoustic energy into frequency domain representations further comprises Fourier transforming each time domain representation to create each frequency domain representation.

3. The method of signal processing to determine acoustic velocity as a function of frequency as defined in claim 1 wherein finding an orthogonal basis of the correlation matrix comprising a plurality of component functions further comprises determining eigenvectors and eigenvalues of the correlation matrix.

4. The method of signal processing to determine acoustic velocity as a function of frequency as defined in claim 3 wherein removing a component function to create a subspace further comprises removing a higher order eigenvector corresponding to received acoustic energy related to the acoustic energy created by the transmitter.

5. The method of signal processing to determine acoustic velocity as a function of frequency as defined in claim 4 wherein removing a higher order eigenvector corresponding to received acoustic energy related to the acoustic energy created by the transmitter further comprises removing a plurality of higher order eigenvectors.

6. The method of signal processing to determine acoustic velocity as a function of frequency as defined in claim 3 wherein removing at least one component function to create a subspace further comprises removing a lower order eigenvector corresponding to received noise.

7. The method of signal processing to determine acoustic velocity as a function of frequency as defined in claim 6 wherein removing a lower order eigenvector corresponding to received noise further comprises removing a plurality of lower order eigenvectors.

8. The method of signal processing to determine acoustic velocity as a function of frequency as defined in claim 1 wherein multiplying a test vector and the subspace to determine whether the estimated acoustic velocity substantially matches the actual earth formation acoustic velocity further comprises calculating an objective function using substantially the following equation:

$$\frac{1}{\left| N_f W_f \right|^2}$$

where N_f is the subspace and W_f is the test vector.

9. The method of signal processing to determine acoustic velocity as a function of frequency as defined in claim 8 wherein the test vector takes substantially the form:

$$W_f = [1\ e^{-jds}\ e^{-j2ds}\ e^{-j3ds}\ \cdot\ e^{-j(n-r)ds}]$$

where d is the distance between the receivers, s is the estimated acoustic velocity, n is the total number of received signals and x is the number of removed eigenvectors.

10. The method of signal processing to determine acoustic velocity as a function of frequency as defined in claim 1 further comprising repeating the multiplying step for a plurality of test vectors comprising a plurality of estimated acoustic velocities.

11. The method of signal processing to determine acoustic velocity as a function of frequency as defined in claim 10 further comprising repeating the creating, finding, removing, multiplying steps for a plurality of corresponding frequencies.

12. In a system for acoustic logging of earth formations where a transmitter creates acoustic signals in the earth formation, a plurality of receivers detect the acoustic signals, and the acoustic signals are transformed into their frequency domain representations, a method of determining slowness of the earth formation as a function of frequency comprising:

calculating a correlation matrix from components of each of the frequency domain representations at a particular frequency;

determining eigenvectors and corresponding eigenvalues of the correlation matrix;

removing at least one eigenvector to create an incomplete basis;

calculating a value of an objective function indicative of the degree to which a test vector may be represented by the incomplete basis, the test vector based on an estimated slowness of the earth formation; and

plotting the value of the objective function as a function of the estimated slowness of the test vector and the particular frequency of the components of the frequency domain representations used to calculate the correlation matrix.

13. The method of determining slowness of the earth formation as a function of frequency as defined in claim 12 wherein removing at least one eigenvector to create an incomplete basis further comprises removing at least one higher order eigenvector, the removed at least one higher order eigenvector corresponding to acoustic signals, and the remaining eigenvectors corresponding to noise.

14. The method of determining slowness of the earth formation as a function of frequency as defined in claim 13 wherein calculating a value of an objective function indicative of the degree to

which a test vector may be represented by the incomplete basis further comprises calculating a value of an objective function indicative of the degree to which the test vector may be represented by the remaining eigenvectors corresponding to noise.

15. The method of determining slowness of the earth formation as a function of frequency as defined in claim 14 wherein calculating a value of an objective function indicative of the degree to which the test vector may be represented by the remaining eigenvectors corresponding to noise further comprises calculating a value of an objective function that approaches zero when the test vector may be substantially represented by the remaining eigenvectors.

16. The method of determining slowness of the earth formation as a function of frequency as defined in claim 15 calculating a value of an objective function that approaches zero when the test vector may be substantially represented by the remaining eigenvectors further comprises calculating the value of the objective function using substantially the following equation:

$$\frac{1}{\left|N_f W_f\right|^2}$$

where N_f is the incomplete basis and W_f is the test vector.

17. The method of determining slowness of the earth formation as a function of frequency as defined in claim 13 further comprising removing a plurality of higher order eigenvectors, the removed higher order eigenvectors corresponding to acoustic signals, and the remaining eigenvectors corresponding to noise.

18. The method of determining slowness of the earth formation as a function of frequency as defined in claim 12 wherein removing at least one eigenvector to create an incomplete basis further comprises removing at least one lower order eigenvector, the removed at least one lower order eigenvector corresponding to noise, and the remaining eigenvectors corresponding to acoustic signals.

19. The method of determining slowness of the earth formation as a function of frequency as defined in claim 18 wherein calculating a value of an objective function indicative of the degree to which the test vector may be represented by the incomplete basis further comprises calculating a value of the objective function that approaches zero when the test vector may not be substantially represented by the remaining eigenvectors.

20. The method of determining slowness of the earth formation as a function of frequency as defined in claim 12 wherein the test vector takes substantially the form:

$$W_f = [1 \; e^{-jds} \; e^{-j2ds} \; e^{-j3ds} \; \cdot \; e^{-j(n-r)ds}]$$

where d is the distance between the receivers, s is the estimated slowness, n is the total number of received signals and x is the number of removed eigenvectors.

21. A method of determining acoustic velocity and frequency dispersion of an earth formation using an acoustic tool, the method comprising:

a) sending acoustic energy into the earth formation from the acoustic tool;

b) detecting the acoustic energy in the earth formation at a plurality of receiver locations on the acoustic tool;

c) creating time series representations of the acoustic energy in the earth formation for each of the plurality of receiver locations;

d) Fourier transforming each of the time series representations to create a plurality of frequency domain representations;

e) creating a vector from values at a selected frequency in each of the plurality of frequency domain representations;

f) creating a correlation matrix from the vector;

g) determining the eigenvectors and eigenvalues of the correlation matrix;

h) removing at least one of the eigenvectors thereby creating a subspace;

i) determining a value that is indicative of the extent a test vector may be represented by the subspace, and wherein the test vector is based on an estimated acoustic velocity of the earth formation;

j) plotting the value as a function of the estimated acoustic velocity of the earth formation and the selected frequency;

k) repeating steps i) and j) for a plurality of estimated acoustic velocities; and

l) repeating steps e) through k) for a plurality of selected frequencies.

22. The method of determining acoustic velocity and frequency dispersion as defined in claim 21 further comprising:

wherein step a) further comprises sending acoustic energy into the earth formation at a depth level of interest; and

m) repeating steps a) through l) for a plurality of depth levels of interest.

23. The method of determining acoustic velocity and frequency dispersion of an earth formation as defined in claim 21 wherein step a) further comprises sending acoustic energy into the earth formation using an acoustic transmitter.

24. The method of determining acoustic velocity and frequency dispersion of an earth formation as defined in claim 21 wherein step b) further comprises detecting the acoustic energy in the earth formation with four acoustic receivers.

25. The method of determining acoustic velocity and frequency dispersion of an earth formation as defined in claim 21 wherein step h) further comprises removing at least one higher order eigenvector, the removed at least one higher order eigenvector corresponding to desired acoustic signals, and the remaining eigenvectors corresponding to noise.

26. The method of determining acoustic velocity and frequency dispersion of an earth formation as defined in claim 25 wherein step i) further comprises applying a test vector to the subspace with the result of the applying being the value indicative of the extent the test vector may be represented by the remaining eigenvectors corresponding to noise.

27. The method of determining acoustic velocity and frequency dispersion of an earth formation as defined in claim 26 wherein applying a test vector to the subspace with the result of the applying being the value indicative of the extent the test vector may be represented by the remaining eigenvectors corresponding to noise further comprises applying substantially the following equation:

$$\frac{1}{\left|N_f W_f\right|^2}$$

where N_f is the subspace and W_f is the test vector.

28. The method of determining acoustic velocity and frequency dispersion of an earth formation as defined in claim 27 wherein the test vector takes substantially the form:

$$W_f = [1\ e^{-jds}\ e^{-j2ds}\ e^{-j3ds}\ \cdot\ e^{-j(n-r)ds}]$$

where d is the distance between the receivers, s is the estimated acoustic velocity, n is the total number of received signals and r is the number of removed eigenvectors.